Reports

Anchor Ice Formation in McMurdo Sound, Antarctica, and Its Biological Effects

Abstract. *Aggregations of ice platelets accumulate below the annual sea ice (subice platelet layer) and on the bottom (anchor ice) to depths of 33 meters. Observations of ice platelets adhering to submerged lines support the conclusion that 33 meters is the lower limit for ice formation in the water column in this area. The rising anchor ice lifts epibenthic fauna and has a pronounced effect on the distribution of the epibenthic organisms.*

Ice formation in McMurdo Sound, Antarctica, usually occurs from late April through late December. Besides the annual sea ice which forms on the surface, two basic types of ice crystals have been described: extremely small crystals and large ice platelets 10 to 15 cm in diameter and 0.2 to 0.3 cm in thickness (*1*, *2*). Since 1962, while fishing or diving through the annual sea ice of McMurdo Sound, we have observed both types of crystals, as well as aggregations of platelets which apparently are formed by individual platelets freezing to each other. These aggregations occur as a layer 0.5 to 4.0 m thick under the annual sea ice, as clusters of platelets frozen to lines which are suspended in the water, and as masses of platelets frozen to the ocean bottom in depths shallower than 33 m (Fig. 1). The latter formation is termed anchor ice (*2*, *3*). A dense association of long-lived sponges and the associated thick spicule matrix generally appears abruptly at this 33 m depth.

Our observations in the austral winters of 1962, 1964, and 1965 indicate that the three types of platelet ice begin to form in July and to disappear in mid-December when the −1.90°C warms to −1.80°C. Intense diving from 10 October to 14 December 1967 disclosed a mat of anchor ice 15 to 40 cm thick at depths of 0 to 15 m. Isolated clumps of anchor ice were found as deep as 33 m, suggesting that this depth is the lower limit of anchor ice formation in the McMurdo Sound region. That the lower limit of ice formation in the water column is approximately 33 m is also indicated by the formation of ice platelets on lines. Lines usually hung 2 weeks without collecting any ice; then suddenly, sometimes in a matter of hours, a heavy, uniform formation of platelets appeared on the upper 30 m of the line. After a period up to about 2 weeks, the ice suddenly ceased to form on the lines. The presence of extremely small ice crystals in the upper part of the water column coincided with the ice formation on the suspended lines. Mechanisms of crystallization and platelet formation have been thoroughly summarized by Bennington (*4*). The interesting aspects of our observations involve the sudden beginning and termination of formation and the apparently consistent lower limit of the platelet ice.

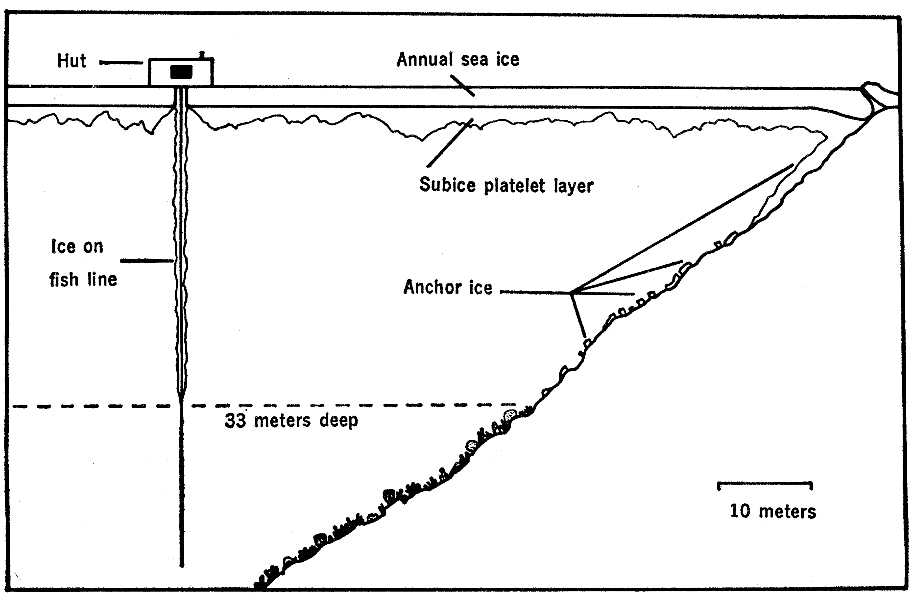

Fig. 1. The lower limit of periodically observed ice formation on suspended lines correlates almost perfectly with that of observed anchor ice and the upper limit of the sponge association.

The temperature and salinity measurements of Littlepage (*2*) during the winter of 1961 to depths of 275 m give many water temperatures below the theoretical freezing point for the recorded salinity. However, the water measured for salinity included minute ice crystals. Littlepage proposed that his salinity measurements were too low because of the presence of these ice crystals, which are composed of fresh water (*2*). The removal of the minute ice crystals would have raised the salinity enough to explain the anomalous temperature observations. However, data on neither the temperature nor the salinity suggest a reason for the restriction of ice to relatively shallow water. Pressure decreases the freezing point of normal seawater 0.0034°C per 10 m increase in depth (*2*). This may partially explain the absence of freezing at the greater depths; however, the relatively slight pressure effect at 33 m does not explain the well-defined lower limit of ice formation below which the water is sufficiently cold (*2*) to freeze in spite of pressure.

Since the density of water with any salinity greater than 24.7 parts per thousand increases with decreasing temperature until the water reaches its freezing point, the cooling surface water becomes more dense than that below it and sinks without freezing. A convection current, in which the relatively warmer water rises and the colder, denser water sinks, results in the top of the water column remaining above the freezing point until the whole column has reached the freezing temperature (*4*). An hypothesized halocline may explain the lower limit of this convection column (*5*). With the beginning of ice formation, the removal of relatively fresh water by crystallization apparently occurs uniformly throughout the convection column, resulting in water with a greater salinity and lower freezing point. This would be an unstable system, as the convection column would become increasingly dense. Eventually, and apparently rather suddenly, the halocline breaks down and the two layers mix. Alternatively, a current could bring in warmer water, accounting for the observed period of no ice formation. Either of these events would explain the sudden termination of ice formation on suspended lines.

Our observations during 1967 suggest that in the shallow waters near Cape Armitage, Hut Point, and the Dailey Islands anchor ice is of considerable biological significance. We frequently observed masses of anchor ice rising from the bottom to the subice platelet layer, carrying numerous motile epibenthic animals. These animals included the echinoid *Sterechinus neumayeri*, the asteroid *Odontaster validus*, the nemertean *Lineus corrugatus*, the isopod *Glyptonotus antarcticus*, various species of pycnogonids, and the fishes *Trematomus bernacchii*, *T. centronotus*, and *T. nicolai*. Although many of these entrapped motile animals were alive, and many, particularly *Odontaster* and *Lineus*, eventually escaped, some became firmly frozen into the subice platelet layer. Obviously, the epibenthic sessile organisms such as bryozoans and sponges raised to the platelet layer have little chance of returning to the bottom. The importance of this uplift is emphasized in areas such as that on the north side of Hut Point, where a light or moderate current persists. In such an area the sponge association is entirely absent above 33 m. On the Cape Armitage shoal, where anchor ice is greatly reduced because of the strong current, a few of the sponges extend into water as shallow as 23 m.

When anchor ice becomes detached due to currents, inherent bouyancy, or a disturbance, it floats to the undersurface of the subice platelet layer carrying with it portions of the substratum which can weigh at least 25 kg. In one instance we watched a 2-m^2 piece of anchor ice lift off the bottom and rise to the subice platelet layer, trapping a *Trematomus bernacchii* as well as some *Sterechinus*, *Lineus*, and *Odontaster*. We frequently observed scattered individuals of *Trematomus*, *Sterechinus*, *Lineus*, *Odontaster*, pycnogonids, and algae frozen into the subice platelet layer. Because

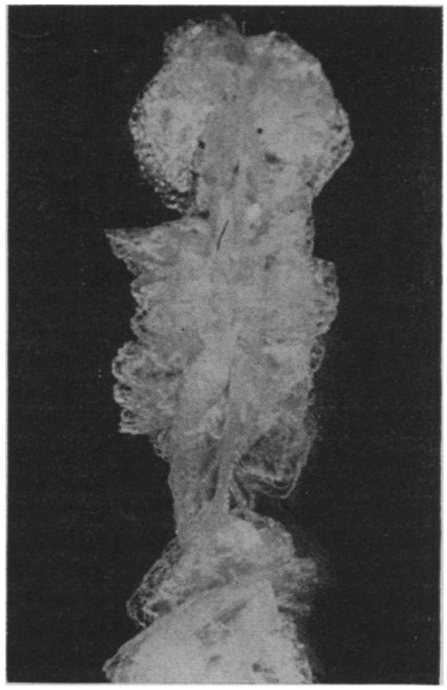

Fig. 2. Ice platelets adhering to a line.

the platelet layer grows at the water-platelet interface and is slowly frozen into solid ice at the platelet–solid ice interface, epibenthic organisms can be found scattered throughout the platelet layer and solid sea ice. In areas where the sea ice is several years old and forms part of the Ross Ice Shelf, this mechanism of sea ice formation followed by ablation may bring many benthic organisms to the surface in an undamaged condition. Pearse first proposed this mechanism (*3*) to explain the presence of fish and delicate benthic invertebrates found in large numbers on the McMurdo Ice Shelf near the Dailey Islands by Swithinbank *et al.* (*6*). However, Debenham (*7*) postulated that the animals are trapped and frozen into the bottom of the ice shelf when it supposedly touches the sea floor. Swithinbank *et al.* (*6*) interpreted their discovery of a large number of nototheniid fishes and benthic invertebrate remains near the Dailey Islands as support of the Debenham hypothesis.

In 1965 Gow *et al.* (*8*) proposed a different explanation for the invertebrates on the surface of the sea ice. They considered the McMurdo Ice Shelf in the vicinity of the Dailey Islands to be of glacial origin and concluded that the invertebrate remains were part of a fossiliferous moraine. Gow's more recent work suggests that the Dailey Island portion of the McMurdo Ice Shelf is indeed sea ice (*9*). His evidence that the invertebrate remains are of a fossil origin can better be interpreted as indicating an anchor ice uplift mechanism. For instance, the delicate pecten *Adamussium colbecki*, as well as being a characteristic of the Taylor Formation (*8*), is currently common living on gravel substrata. Also, the lack of flesh in the specimens found on the surface of the ice shelf does not necessarily indicate that they are derived from preexisting fossiliferous deposits since the sea bottom is covered with shellfish valves. Finally, the extremely fragile nature of the sessile invertebrates found undamaged on the surface of the ice shelf argues strongly against the theory that they were incorporated into a moraine, where they would more likely have been crushed.

We have found that while fish are occasionally trapped in the anchor ice, their presence on the surface is often attributable to the feeding habits of the common Weddell seal, *Leptonychotes weddelli*, which often brings the large nototheniid fish *Dissostichus mawsoni*, as well as various other smaller fishes, into the proximity of the ice holes to eat them. We have frequently observed the seal to lose all or part of the fish in platelet ice in the hole. These observations support the argument of Gow *et al.* (*8*) that the fish found at the Dailey Islands were actually left by seals near the top of a tide crack and eventually exposed by surface ablation (*10*).

PAUL K. DAYTON
GORDON A. ROBILLIARD
Department of Zoology, University of Washington, Seattle 98105
ARTHUR L. DEVRIES
Food Science and Technology, University of California, Davis

References and Notes

1. T. V. Hodgson, *British Nat. Antarct. Exped. 1901–1904, Natur. Hist.* (1907), vol. 3.
2. J. L. Littlepage, *Antarct. Res. Ser.* **5**, 1 (1965).
3. J. S. Pearse, *Sci. Amer.* **207**, 12 (1962).
4. K. O. Bennington, *J. Glaciol.* **4**, 669 (1963).
5. I. Hela, in *Arctic Sea Ice* (Nat. Acad. Sci.–Nat. Res. Council Publ. 598, Washington, D.C., 1958).
6. C. W. M. Swithinbank, D. G. Darby, D. E. Wohlschlag, *Science* **133**, 764 (1961).
7. F. Debenham, *Quart. J. Geol. Soc. London* **75**, 51 (1920).
8. A. J. Gow, W. F. Weeks, G. Hendrickson, R. Rowland, *J. Glaciol.* **5**, 813 (1965).
9. A. J. Gow, *Antarct. J. U.S.* **2**, 121 (1967).
10. We must emphasize that these were relatively limited observations restricted to the Hut Point area of the McMurdo Sound region.
11. Supported by NSF GA 45 (Stanford University to D. E. Wohlschlag) and NSF GA 1187 (University of Washington to R. T. Paine). Technical help from the U.S. Navy Photo Lab at McMurdo Sound, Antarctica, is acknowledged. We thank K. O. Bennington, R. T. Paine, V. Peckham, and L. Wilmot for help in the preparation of this report and R. Allison, A. J. Gow, G. L. Kooyman, and J. L. Littlepage for reading the manuscript. S. P. Heller made Fig. 1.

29 August 1968; revised 22 November 1968